

# Chapter 16

## On the Drawing Board

*James H. Tidwell*

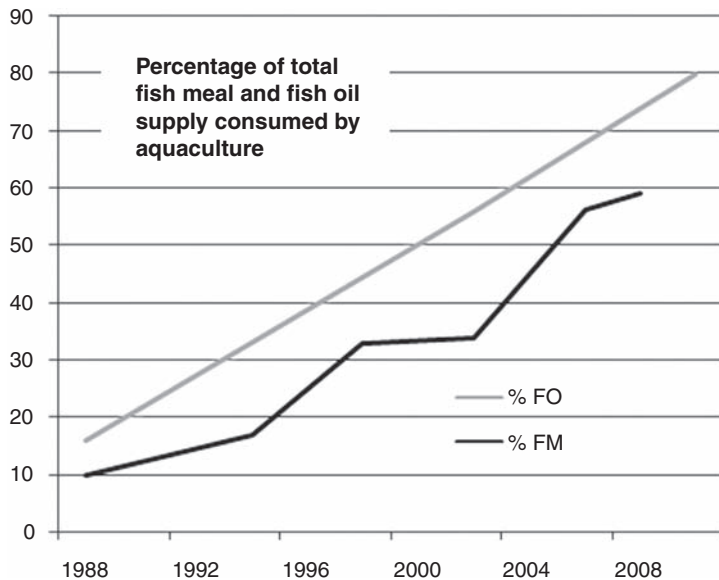
Aquaculture has its work cut out for it. It is expected to increase production levels over 75% in the next twenty-five years (from 48 million tonnes in 2005 to 85 million tonnes in 2030) with a minimum impact on the environment and a maximum benefit to society (Subasinghe 2007). This is no small task. As we look into aquaculture's crystal ball, certain trends can be seen to be developing. These include: (a) a continuing trend toward intensification, (b) a continuing trend toward new species development and diversification, (c) continued development of new production systems and diversification, (d) increased influence of market forces on production, and (e) increased government regulation with (we hope) improved regulatory procedures (Subasinghe 2007).

### 16.1 Future trends

---

#### 16.1.1 Fish meal and fish oil supplies

These trends seem fairly inevitable. However, there are other concerns that will impact aquaculture's future. One of the issues that have received much attention, discussion, and press in recent years is the use of fish meal and fish oil in aquaculture diets. Indeed, aquaculture has continued to absorb an increasing proportion of the supply of these important, if not essential, feed ingredients. In fact, when the trends of consumption are projected into the future (a statistically

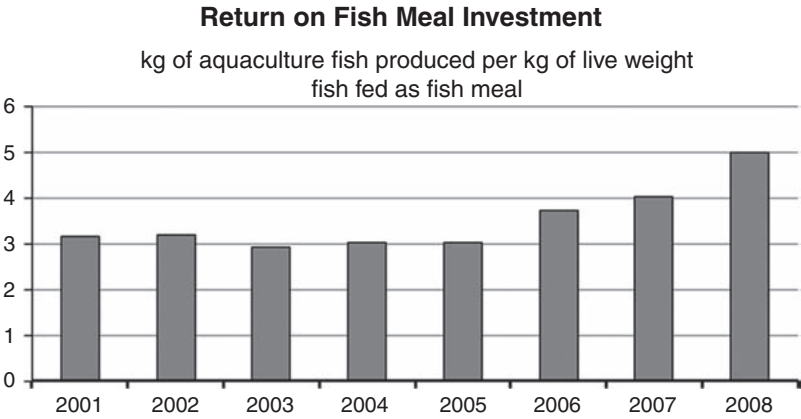


**Figure 16.1** The percentage of fish oil and fish meal supply consumed by the aquaculture industry from 1988 to 2008.

dangerous practice) we can get results that indicate that aquaculture will consume *all* fish meal production (fig. 16.1) in a very few years. This projection has been termed the “fish meal trap” (New 1999). To be more accurate, it might be better described as the fish oil trap, as fish oil supplies are projected to become limiting before fish meal does (fig. 16.1).

In 2006, aquaculture consumed 3 million tonnes or 56% of world fish meal production (Tacon & Metian 2009). That same year, aquaculture utilized 87% of the world’s fish oil production (Tacon & Metian 2009). Also of concern is the additional 5 to 6 million tonnes of low value/trash fish used as direct feeds for many aquacultured species in Asia (Tacon *et al.* 2006). These numbers and projections are indeed troubling. As we have seen, this “trap” could represent a major impediment to aquaculture growth and expansion, which are needed to provide the increasing demands for foodfish. Many environmental groups have used these figures to make claims that aquaculture is causing the collapse of these fish-meal fisheries and actually produces less fish than it utilizes. However, recent reexamination of these models and calculations shows that feed-based aquaculture produces *twice* as much fish as it uses (Tacon & Metian 2009). If the large numbers of aquacultured species that do not depend on manufactured diets are included, aquaculture as an industry actually produces three to five times as much fish as it consumes (fig. 16.2).

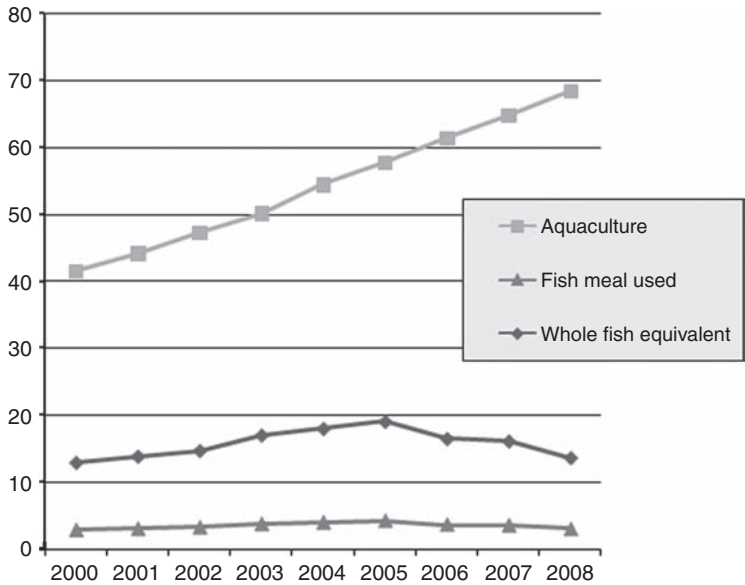
If we look at trends for these “industrial” fisheries targeted toward fish meal production (fig. 16.3), we see that they are some of the best managed fisheries in the world (Tidwell & Allan 2001). With continued management they can continue to produce approximately 30 million tonnes per year, sustainably, for



**Figure 16.2** The amount of total fish generated by aquaculture divided by the whole fish equivalent of fish meal (i.e., the return on the fish meal investment) from 2001 to 2008.

years to come (barring external perturbations such as global warming). Even if aquaculture continues to grow, management controls will not allow harvest pressures to be increased or allow these fisheries to be depleted.

Also, much has been made of “fishing down the food web” (Pauly *et al.* 1998). By some estimates over 90% of the oceans’ large predators have been removed by human fishing activities. Populations of predatory marine mammals have also decreased. With these factors considered, proper cropping of these short-lived,



**Figure 16.3** Total aquaculture production, fish meal used, and whole fish equivalent based on fish meal used by aquaculture from 2000 to 2008.

highly fecund forage species might actually be needed to prevent over population in the absence of predatory pressures

Another criticism by environmental groups has been that these harvested “fish meal” fish could be better utilized as direct food for humans rather than feeding them to other fishes. As with many issues, the issues and answers are complex. There have been examples where the increased demand for pelagic fish by the animal feed industry has decreased the availability of fresh fish for poor communities (Hasan 2007). However, other studies have shown that reduction (fish meal) fisheries can also benefit locals by contributing to animal production enterprises, which generate jobs and improve living standards and food security (Hecht & Jones 2007). Actual impact differs largely on the region being considered. In Africa and Asia, the species used for reduction to fish meal, or direct feeding to aquacultured animals, do have potential for direct human consumption, while those species used in Europe to produce fish meal are not really suitable for any other uses (Huntington 2007).

Will this “fish meal/fish oil trap” stifle aquaculture development? Or will a better understanding of the specific nutritional requirements of aquaculture species, coupled with more information on alternative ingredients, reduce aquaculture’s dependency on fish meal production? I tend to believe the latter. Research indicates that once we understand a species’ nutritional requirements and tolerances, the fish meal and fish oil content of aquafeeds can be reduced substantially. For salmon it is estimated that at least 50% of the fish meal and 50 to 80% of fish oil can be replaced with vegetable substitutes. For marine fish, 30 to 80% of fish meal and 60% of fish oil used could come from alternative sources (Royal Commission on Environmental Pollution 2005). This can include use of terrestrial protein crops such as soybean meal, but examples also include increased utilization of by-catch from commercial fisheries, as well as wastes and offal from fish processing (Hardy *et al.* 2005). When we do not yet know the specific nutritional requirements of a culture species, nutritionists tend to “over formulate.” That means we include very high protein and fish meal levels to ensure they meet the animals’ requirements (which are not yet known). However, once the research is conducted to delineate the animals’ nutritional requirements, species-specific diets can be formulated, which greatly improve nutrient retention efficiency and increase the ability to utilize alternative ingredients. An example is research at our lab on diets for the largemouth bass (*Micropterus salmoides*). The diets being used by commercial producers contained 40% fish meal, while our research has determined that fish meal inclusion could be reduced to  $\leq 8\%$  without decreasing growth or feed conversion efficiency (Cochran *et al.* 2009).

### 16.1.2 Climate change

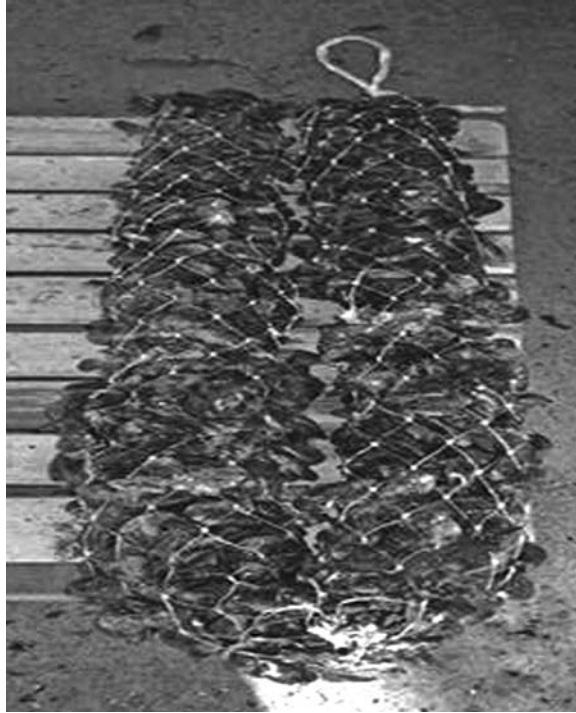
What impacts will climate change have on aquaculture production? While still debated in the forums of politics and television news, the overwhelming majority of scientists agree that the trends are real. What they do not yet agree on is the pace and subsequent effects. Because of the complicated interrelationships within

the planet's ecology, there will likely be a patchwork of impacts. However, in the big picture, it is obvious that conditions *will* in fact change and that these changes will influence how aquaculture develops in the near and distant future. According to Soto and Brugere (2008), climate change "is characterized by its unpredictability and the large uncertainty that has to be factored in all models and the reaction of ecosystems." Other related factors that will undoubtedly affect aquaculture's future include recent rapid global increases in energy prices and grain prices.

According to Nomuva (FAO-Fisheries) and Steiner (United Nations Environment Programme, UNEP) in 2009, during a climate change discussion in Bonn, Germany, "the challenges and threat" of climate change must be a top priority for world leaders. Part of that priority is ensuring healthy aquatic ecosystems. Likely impacts include changes in air and sea surface temperatures, changes in rainfall amounts and patterns, acidification of ocean waters, rises in sea levels, and resulting changes in estuaries and shoreline communities, and increased frequency and intensities of climate patterns (such as El Niño) and storms (such as cyclones and hurricanes; UNFCCC-COP-15 2009).

Based on these changes, the zones considered optimal for the production and reproduction of different species will likely move (Soto & Brugere 2008). It is predicted by some that aquaculture will in fact be disproportionately affected by climate change, based on the fact that it raises poikilothermic (cold blooded) animals, and the fact that the vast majority of production is in open and semi-open systems, which operate at ambient temperatures and have no capacity for temperature control (UNFCCC-COP-15 2009). However, even within aquaculture there can be winners and losers. In a warmer world, tropical ecosystem productivity may likely be decreased, while higher latitudes could actually benefit (Soto & Brugere 2008). However, there are still many unknowns such as species invasions (in fact, who is resident and who is the invader may be redefined as temperature zones shift) and the occurrence and virulence of diseases change (Soto & Brugere 2008).

So what can be done? The United Nations Environment Programme (UNEP) gives a number of recommendations (see the end of this chapter for a list of recommended actions) for both capture fisheries and aquaculture (UNEP 2009). The first step is to develop a better understanding of the interworkings of both the production system and its environment by implementing an Ecosystem Approach to Aquaculture (EAA). By understanding the interaction of the farm, the water body (and its watershed), and the global market (and requisite transportation), it is felt that resilience to change can be increased (Soto & Brugere 2008). Next, we can reduce the dependence on raising carnivorous species. We can also decrease the impact of those we do produce by genetically selecting for strains that are able to utilize lower protein and fish meal levels and higher levels of by-products. We can also improve the diets themselves through improved manufacturing processes (Soto & Brugere 2008). We should increase the production of "extractive" species that can actively remove waste products such as nitrogenous wastes, carbon, and phosphorous, thereby improving the environment (bivalves and microalgae are examples; fig. 16.4).



**Figure 16.4** Mussels, which can act as extractive species to remove algae and excess nutrients near cage or net pen production.

The next step is integrating these extractive species into the production systems for food species to lessen the environmental impact and improve the economic viability, or both. Another example of combining systems is that while many types of pond-based aquaculture actually suffer from excessive production of algal biomass (Brune *et al.* 2003; fig. 16.5), there are efforts elsewhere to mass-produce algae in ponds for biofuels. A continuous partial harvest of algae from aquaculture systems could potentially improve the pond environment for aquaculture production while simultaneously producing a secondary algae crop for biofuels production.

Another major initiative related to climate change will likely be the continued development of new culture species. As conditions change in a particular locale, switching to another species (better adapted to the new conditions), rather than moving the production system, may be more practical. Research into the genetic improvement of both new and traditional species will also be especially important. This approach has the potential to shift the animals' temperature tolerance, oxygen tolerance, disease resistance, and dietary requirements—all of which are important in improving aquaculture's adaptation to climate change.

A third area needed to enhance the adaptability of aquaculture-based crops to climate change is in the area of public policy. How have we dealt with



**Figure 16.5** A pond with and excessively dense algae bloom.

uncertainty in other crops? Improved forecasting, crop insurance, and risk management are all concepts that have been used in terrestrial crops for years and could play an increasing role in aquatic crops. Many of the future changes in aquaculture production will be driven by sustainability. This has to include economic sustainability as well as environmental sustainability. A balance of both is important.

### 16.1.3 Aquaculture to reduce CO<sub>2</sub>

Aquaculture may even serve as a cure, or at least a treatment, for the ills of other industries. While there are major concerns over the future pricing and availability of petroleum, there are still substantial coal reserves in many parts of the world. However, coal has the drawback of releasing carbon, which has been locked away for millions of years, back into the atmosphere as CO<sub>2</sub> (fig. 16.6). One approach being investigated is to use algae as a biological “scrubber” to strip the CO<sub>2</sub> from the flue gas of coal-fired power plants, before it is released to the atmosphere. These algae, whose growth is enhanced by the increased CO<sub>2</sub> concentration, can then be harvested to produce biofuels. It is reported that a hectare devoted to algae production can yield 50,000 liters of biofuel, compared to 350 liters from a terrestrial crop such as sunflower seeds (Penwarden 2006). While this approach would actually represent carbon recycling, another approach is to use marine algae (*Coccolithophorids*) to absorb the CO<sub>2</sub>,



**Figure 16.6** A coal-fired power plant.

convert it to calcium carbonate (limestone), and permanently sequester the carbon into a form, which could potentially be used as a building material (Romanosky 2000).

#### **16.1.4 Improved genetics**

Another future development will likely be “designer strains” of animals specifically suited for the production systems they are being raised in. At present, only 1 to 2% of the animals used in aquaculture are genetically improved (Gjedevem 1997), with most aquacultured species being only slightly removed from the wild. As animals become selected for improved production in aquaculture, the process will be further refined until strains specific to different production systems are developed. Just as we have different strains of chickens depending on whether they will be raised outside (i.e., pastured poultry) or indoors in high-density chicken houses, we will have specific genetic strains of shrimp used in ponds that are different from shrimp that are used in super-intensive indoor systems.

### 16.1.5 Production intensification

As stated previously, there is a general trend toward production intensification. In ponds, production intensification has been an incremental process over the past fifty years. Production was originally limited to approximately 500 kg/ha, primarily by the availability of natural foods. As supplemental feeds were added, production was increased threefold to 1,500 kg/ha when it then became constrained by the pond's ability to provide oxygen reliably (when feeding rates exceeded 30 kg/ha/day). With the advent of mechanical aeration, pond production rates again tripled with an average carrying capacity exceeding 4,500 kg/ha. The limiting factor in pond intensification is now primarily the accumulation of nitrogenous waste products. Further intensification of pond production will require methods to more rapidly and/or efficiently remove or convert nitrogenous waste products within the pond system.

Different approaches to accomplish this are under development. Currently, most pond systems rely on nitrifying bacteria to convert the waste product ammonia to less toxic nitrate through nitrification. The nitrate is then assimilated by the pond's algal population. Algae can also directly assimilate ammonia in its ammonium form. However, these processes become limited by the availability of light (to drive photosynthesis), oxygen, or other factors such as micronutrients, to rates that limit the further intensification of pond systems (Hargreaves & Tucker 2003). A new pond-management approach has gained traction in recent years. In this approach, the pond ecology is shifted away from autotrophic algae toward heterotrophic bacteria whose populations are not light limited (see chapter 12). This shift is encouraged by manipulation of the carbon/nitrogen ratios in the system. Most of these systems are carbon limited, so when sufficient carbon is supplied (often in the form of a carbohydrate, such as sugar) the system can rapidly and efficiently remove nitrogen from the water by converting it directly into bacterial biomass (Avnimelech 1999). The bacterial "floc" that is formed can often serve as supplemental food for some filter feeding, scavenger, or detritivore species. Results of this system indicate that production may again be tripled with rates of near 15,000 kg/ha being reported (Boyd & Clay 2002).

Other approaches to this same problem include maximizing the efficiency of algae-based systems. In a traditional pond system, heavy phytoplankton populations limit light penetration to just a few centimeters so that photosynthesis is restricted to just this photic zone. To address this restriction, a new modified pond system has been developed that maximizes the potential of algal assimilation of nitrogen by directing the flow of the water across shallow zones to maximize light contact and photosynthetic rates (Brune *et al.* 2003). This system, known as the partitioned aquaculture system (PAS), is described in much more detail in chapter 13. Other approaches that might be considered in the future include hybridizing components from other systems into the pond production systems. Examples could be adding biofilters to the pond systems, adding a hydroponic component to flow the water through, or adding a floating island of plants within the pond itself.

### 16.1.6 Increased use of marine systems

Although the majority of aquaculture production for food currently occurs in freshwater ponds, much of the future of the industry looks back to the sea. A large part of the financial support for aquaculture research in the United States is now being directed to marine systems and species. So what do we see, in terms of new marine aquaculture production technologies?

As with other types of production, much of the development will focus on sustainability and the reduction of environmental impact. Also, it will likely be a matter of evolution, not revolution. We will see existing systems modified, improved, or combined in new and innovative ways to address problems (either real or perceived).

### 16.1.7 Evolution of sea cages

Cage culture has evolved over millennia and it continues to evolve. It began with capture fisheries. If a fisherman caught more than he could use or sell, he needed to “warehouse his inventory.” If this was a time or place where refrigeration was not an option, what could be done? For historic ocean-capture fisheries like cod, the best option was to process fish and pack them in salt. For freshwater fishermen in the rivers and lakes of Asia, it was to hold the live animals in baskets (fig. 16.7). While holding them, you might as well try to put some extra weight on them by feeding them. Then why not diversify to capturing juveniles during the spawning season and growing them out on foods you provide?

As these concepts moved to protected coastal waters, they evolved from fenced-in enclosures of mud bottoms to deeper areas where currents and depth



**Figure 16.7** Bamboo baskets that were used to catch, store, and later raise fish as precursors to fish cages.

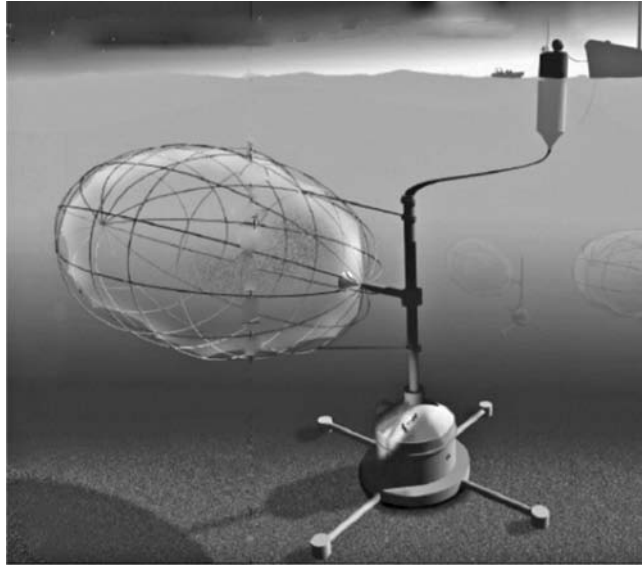


**Figure 16.8** An ocean net pen in Corsica.

could flush away or dilute waste products (fig. 16.8). However, directly under these stationary cages waste products can accumulate, so there has been a push to move the cages out into what are known as “high energy” environments to better supply the cages with high-quality water and disperse any waste products. This, too, is difficult. As we move out of the protected fjords and into the unprotected coastal areas, we move into a more punishing environment.

So how do we “evolve” the system to deal with these issues? One approach has been to stay in the protected waters, but try to deal with the wastes. Mariculture Systems in the United States markets a system where the permeable net pens are replaced by impermeable enclosures. Water is pumped into these floating reservoirs. The intakes for the incoming water can be positioned to take advantage of differences in temperatures and water quality parameters at different depths. The water is pumped into the cone-shaped enclosures in a way as to set up a constant swirl whose speed can be manipulated based on variables such as fish size. The swirl will also, through the Venturi effect, move solids such as fish feces to the bottom of the culture vessel allowing the solids to be collected and removed or treated. This system has taken the traditional net pen system and hybridized it with many of the components of the recirculating aquaculture systems discussed in chapter 11.

Another approach to dealing with the limitations of net pen culture has been to fully “seal” the fish inside the net pen enclosure. Traditional designs extended to or above the water’s surface where the fish were open to the air to allow feeding and so on. By adding another net pen on the top, the fish were now fully sealed inside the enclosure. With the fish now fully sealed inside the cage, it



**Figure 16.9** A fully enclosed ocean net pen. Illustration courtesy of Richard Langan.

can be lowered underwater to escape the harsh wave action of the surface, or it can be lowered even deeper, should environmental factors like oil spills or toxic algae blooms make this action advantageous. This fully enclosed design is seen in such models as the Aquapod (Ocean Farm Technologies), OceanGlobe (KSAS), and SeaStation (OceanSpar; fig. 16.9). With these designs come hardware and software for monitoring, feeding, and even self-generating power (fig. 16.10).

So what does the future hold? Poal Lader, a SINITEF Fisheries and Aquaculture research scientist sees a “farm” that runs itself. Instead of free-ranged fish, he sees free-ranged farms; large autonomous fish farms that can move about. There would be a base station that would be moored to the bottom. It would monitor the conditions in the region in terms of oxygen levels, temperature, weather, nutrients, and other environmental variables. This information would be shared with enclosed culture modules that could move around to take advantage of the best conditions. It could even be used to transport the fish closer to their intended markets as they approach harvest size.

This vision of the future may not be as far away as it sounds. Cliff Goady, Director of the Massachusetts Institute of Technologies, Sea Grant Offshore Aquaculture Engineering project has developed large, low rpm electric propellers, which allow enclosed net pens to be moved and maneuvered underwater. They have been tested under commercial conditions off the coast of Puerto Rico.

### 16.1.8 Trophic integration

Related to sustainability and hybrid systems is the concept of trophic integration. The basic idea is to combine the culture of extractive species, such as shellfish



**Figure 16.10** A enclosed net pen with monitoring and energy generation. Photo courtesy of the Atlantic Marine Aquaculture Center, University of New Hampshire.

or plants, with fed species. The theory is that the extractive species will act as a “nutrient scrubber” to clean up the wastes generated by the fed species. The environment will be protected and the growth and production of the extractive species will be increased by the increased supply of nutrients. Much of the work in this area has been in marine systems and has been directed toward ameliorating the impact of sea cages, such as those used for salmon production. Research has been going on for about twenty years in North America and other regions such as Israel and South Africa. Most have involved small-scale study systems, but commercial-scale systems are now operating. However, in China, the concept is hundreds of years old and operates on the scale of entire bays, with fish being co-cultured with scallops, abalone, and kelp. In Canada, mussels and kelp are raised around salmon cages. In South Africa, abalone are cultured in onshore tanks and their wastewater is used to culture seaweeds. Such an approach reduces the release of pollutants and nutrients into the environment. It also yields additional crops for additional income. This increases diversification, which can be important for improved cash flow and risk management.

### 16.1.9 Integration of aquatic and terrestrial systems

Another concept of integrated aquaculture is to combine aquaculture with terrestrial agriculture. Integrated agriculture-aquaculture (IAA) systems have been used in Asia for centuries. There are many examples of variations on this concept with livestock-fish integrations of chicken-, duck-, and pig-based systems, usually combined with carp species. There are also rice-fish, rice-shrimp, and rice-prawn systems.

All of these integrated systems show how complimentary species can be used to benefit both the producer and the environment. However, they can also be more complicated to operate than fed monoculture systems. Regulatory and/or financial incentives may be required in some situations to encourage their adoption.

### 16.1.10 Artificial floating islands

In the future, we will continue to see a blurring of the lines among systems and the hybridization of components from different systems, and even among major categories of systems. An example could be the use of artificial floating islands (AFI). These are vegetated floating platforms that have been used in ponds, lakes, and reservoirs (fig. 16.11). These AFI units can provide several ecological



**Figure 16.11** A floating island.

services, including improvement of water quality, enhancement of habitat, and control of shoreline erosion. Their use in Japan dates back to the 1920s, and interest in them has increased in recent years. However, little of the research on AFIs has been published in English, limiting their adoption in many areas.

There are two major categories of AFIs: dry AFIs (which have the plant roots contained within an enclosure) and wet AFIs (which have the plant roots extending down into the water). Vegetation in these systems includes cattails (*Typha latifolia*), yellow iris (*Iris psuedacorus*), and common reed (*Phragmites australis*). Oshima *et al.* (2001) showed that AFI could reduce both total-nitrogen and chlorophyll-A in a pond system. To my knowledge, they have not yet been tested in an aquaculture system.

### 16.1.11 Species diversification

Another major aspect of the future for aquaculture will be the continuing development of new species. Even though a relatively staggering number of species are already cultivated (>400), the number will undoubtedly continue to increase. This will be driven not only by the continuing development of new production technologies, but also by the expansion of aquaculture into new geographic regions. Since the use of nonindigenous species is discouraged and even prohibited in some places, there will be increased pressure to develop native species for commercial production. An example has been the multidisciplinary and multi-institutional program in Brazil to develop the indigenous freshwater prawn *Macrobrachium amazonicum* as an alternative to the nonnative *Macrobrachium rosenbergii* (Moraes-Valenti & Valenti 2010).

Other forces will also drive an increase in the number of species being raised. Not all aquaculture animals are grown as food. The ornamental fish trade exceeds US\$15 billion/year in total economic impact (FAO 2005). The nature of the business is that it is highly desirable to continue to develop new “products” to be sold. As stated by Hill and Yanong (2002), “the aquarium hobby thrives on novelty.” This can be addressed not only by developing new genetic strains of traditional species, but also by the use of new culture species. It is estimated that there are already over 8,000 marine species used in the ornamental trade (FAO 2005).

We will also see new species being used in our more traditional culture systems. For example, in Canada the development of new aquaculture species is predicted to provide an economic impact of US\$880 million by 2020. These species include Atlantic cod, Atlantic halibut, Arctic char, and sablefish. A major contributor to their rapid development is the use or adaptation of hatchery, nursery, and growout technologies previously developed for traditional species.

### 16.1.12 Aquaculture of nonfood products

Another driving force for species diversification will be new uses for aquatic animals and plants beyond food and ornamental applications. Production of



**Figure 16.12** Photobioreactors for raising algae. Photo courtesy of Sam Morton, Center for Applied Energy Research, University of Kentucky.

aquatic species for biofuels has already redirected a number of aquaculture production systems from their previous use in food fish production. Examples include leases offered to owners of catfish ponds in Mississippi to be used for algae production and the shift of tank-based Kent SeaTech to Kent BioEnergy. The partitioned aquaculture system (PAS) discussed in chapter 13 is now also being used to produce algae for biofuels.

Other examples of diversification include production of algae for long-chain omega-3 fatty acids. As demand for these compounds has increased, the need to identify and develop alternative sources has also increased. Even when harvested as fish oil, the ultimate producer of these fatty acids in the food chain was actually algae. Direct production of algae for these fatty acids could be potentially more efficient. New production systems have been developed to produce pure cultures of certain algae strains on a commercial scale. One of the most popular is the photobioreactor (fig. 16.12). There are a number of different styles including vertical tubes, horizontal tubes, flat panels, spiral tubes, raceway systems, and spheres.

Other areas of expansion and diversification of aquaculture systems include the production of therapeutic compounds (i.e., “farmaceuticals”). It is estimated that more than 50% of the drugs in use today originated from natural sources (i.e., plants, animals, or microorganisms). Many were originally isolated from soil microbes (such as penicillin). In fact, more than 120 pharmaceuticals derived from soil organisms are still prescribed today (Fenical 2006). However, we are

now realizing that there may be a much larger “pool” of natural compounds to evaluate in marine ecosystems. Of the thirty-six Phyla of life, seventeen are found in terrestrial environments, but twice as many (thirty-four) live in marine ecosystems. Early work on development of drugs from marine sources began in the 1950s (Bergmann & Feeney 1951). The pace of evaluation rapidly increased in the 1990s, when the National Cancer Institute initiated a dedicated drug discovery program (Cragg *et al.* 2005). By 2006, there were over thirty marine-derived molecules in preclinical development or being used in clinical trials against cancer (Fenical 2006). In addition, there are also marine-sourced drugs in clinical trials for acute pain, asthma, Alzheimer’s disease, malaria, infections, and inflammation.

Discovering a compound that shows bioactivity is not itself sufficient to justify its entrance into the drug development process. There must also be a cost-effective source of the candidate compounds. Sipkema *et al.* (2005) conducted an economic and technical analysis of potential production methods for producing pharmaceutically active compounds from sponges. They found that traditional mariculture methods (net bags on longlines) and tank culture were both superior to cell culture for the large-scale production.

### 16.1.13 Conclusion

As has been said, the only thing that is constant is change. The growth of aquaculture is essential to provide a steady supply of high-quality protein and healthy fatty acids for a rapidly increasing human population. However, the production methods used will need to be environmentally and economically sustainable, under conditions that will likely change substantially in the next fifty years. Major perturbations will likely include climate change and volatility in the costs of inputs such as feed and energy. It is very likely that the aquaculture production systems of the twenty-second century will include new and unique combinations of today’s technologies as well as new technologies we have not yet imagined. It should be an interesting ride.

#### What can we do now?

- Implement comprehensive and integrated ecosystem approaches to managing coasts, oceans, fisheries, and aquaculture; to adapting to climate change; and to reducing risk from natural disasters.
- Move to environmentally friendly and fuel-efficient fishing and aquaculture practices.
- Eliminate subsidies that promote overfishing and excess fishing capacity.
- Provide climate change education in schools and create greater awareness among all stakeholders.
- Undertake assessments of local vulnerability and risk to achieve climate proofing.
- Integrate aquaculture with other sectors.
- Build local ocean-climate models.

- Strengthen our knowledge of aquatic ecosystem dynamics and biogeochemical cycles such as ocean carbon and nitrogen cycles.
- Encourage sustainable, environmentally friendly, biofuel production from algae and seaweed.
- Encourage funding mechanisms and innovations that benefit from synergies between adaptation and mitigation in fisheries and aquaculture.
- Conduct scientific and other studies (e.g., economic) to identify options for carbon sequestration by aquatic ecosystems that do not harm these and other ecosystems.
- Consider appropriate regulatory measures to safeguard the aquatic environment and its resources against adverse impacts of mitigation strategies and measures.

## 16.2 References

---

- Bergmann, W. & Feeney, R. (1951) Contributions to the study of marine products. XXXII The nucleotides of sponges. I. *Journal of Organic Chemistry* 16(6):981–7.
- Boyd, C.E. & Clay, J.W. (2002) *Evaluation of Belize Aquaculture, Ltd: A Superintensive Shrimp Aquaculture System*. Report prepared under the World Bank, Network of Aquaculture Centers in Asia-Pacific, World Wildlife Fund and Food and Agriculture Organization of the United Nations Consortium on Shrimp Farming and the Environment.
- Brune, D.E., Schwartz, G., Eversole, A.G., Collier, J.A. & Schwedler, T.E. (2003) Intensification of pond aquaculture and high rate photosynthetic systems. *Aquacultural Engineering* 28:65–86.
- Cochran, N.J., Coyle, S.D. & Tidwell, J.H. (2009) Evaluation of reduced fish meal diets for second year growout of the largemouth bass, *Micropterus salmoides*. *Journal of the World Aquaculture Society* 40(6):735–43.
- Cragg, G.M., Kingston, D.G.I. & Newman, D.J. (2005) *Anticancer Agents from Natural Products*. CRC Press, Boca Raton.
- FAO (2005) *Ornamental Fish*. Topics Fact Sheet, Fisheries and Aquaculture Topics. FAO, Rome. <http://www.fao.org/fishery/topic/13611/en>.
- Fenical, W. (2006) Marine pharmaceuticals: Past, present, and future. *Oceanography* 19(2):110–19.
- Gjedrem, T. (1997) Selective breeding to improve aquaculture production. *World Aquaculture* 28(1):33–45.
- Hardy, R.W., Sealy, W.M. & Gatlin, D.M. (2005) Fisheries by-catch and by-product meal as protein sources for rainbow trout *Oncorhynchus mykiss*. *Journal of the World Aquaculture Society* 36(3):393–400.
- Hasan, M.R. (2007) Use of wild fish and/or other aquatic species to feed cultured fish and its implications to food security. *FAO Aquaculture Newsletter* 37:30–2.
- Hecht, T. & Jones, C.L.W. (2007) *The use of wild fish as feed in aquaculture and its implications for food security and poverty alleviation in Africa and the Near East*. Review prepared for FAO, Rome.
- Hill, J.E. & Yanong, R.P.E. (2002) Freshwater ornamental fish commonly cultured in Florida. University of Florida Institute of Food and Agricultural Sciences, *Circular* 54:1–6.

- Huntington, T. (2007) *Regional Review for Europe: Use of Wild Fish and/or Other Aquatic Species to Feed Cultured Fish and Its Implications to Food Security and Poverty Alleviation*. Review prepared for FAO, Rome.
- Moraes-Valenti, P. & Valenti, W.C. (2010) Culture of the Amazon River Prawn, *Macrobrachium amazonicum*. In *Freshwater Prawns: Biology and Farming* (Ed. by M.B. New, W.C. Valenti, J.H. Tidwell, L.R. D'Abramo & M.N. Kutty), pp. 485–501. Wiley-Blackwell, Oxford.
- New, M.B. (1999) Global aquaculture: Current trends and challenges for the 21st Century. *World Aquaculture* 30(1):8–13, 63–79.
- Oshima, H., Karasawa, K. & Nakamura, K. (2001) Water purification experiment by artificial floating island. *Proceedings of the Japan Society on Water Environment* 35(146). (In Japanese).
- Pauly, D., Christensen, V., Dalsgaard, J., Foese, R. & Torres Jr., F. (1998) Fishing down marine food webs. *Science* 279(5352):860–3.
- Penwarden, M. (2006) Carbon capture: The algae alternative. Website Matter Network. <http://www.matternetwork.com>. Accessed June 10, 2008.
- Romanosky, R. 2000. Cal State to explore the use of marine algae to soak up carbon dioxide. DOE's sequestration program continues to expand. Fossil Energy Techline. US Department of Energy. December 11, 2000.
- Royal Commission on Environmental Pollution (2005) *Turning the Tide*. The 25th Report Addressing the Impact of Fisheries on the Marine Environment. The Stationery Office, Norwich.
- Sipkema, D., Osinga, R., Schatton, W., Mendola, D., Tramper, J. & Wijffels, R.H. (2005) Large-scale production of pharmaceuticals by marine sponges: Sea, cell or synthesis? *Biotechnology and Bioengineering* 90(2):201–22.
- Soto, D. & Brugere, C. (2008) The challenges of climate change for aquaculture. *FAO Aquaculture Newsletter* 40:30–2.
- Subasinghe, R.P. (2007) Aquaculture status and prospects. *FAO Aquaculture Newsletter* 38:4–7.
- Tacon, A.G. J. & Metian, M. (2009) Fishing for aquaculture: Non-food use of small pelagic forage fish-a global perspective. *Reviews in Fishery Science* 17(3):305–17.
- Tacon, A.G.J., Hasan, M.R. & Sugasinghe, R.P. (2006) Use of fishery resources as feed inputs for aquaculture development: Trends and policy implications. *FAO Fisheries Circular No. 1018*. FAO, Rome.
- Tidwell, J.H. & Allan, G. (2001) Fish a food: Aquaculture's contribution. *EMBO Reports* 2:958–63.
- United Nations Environment Programme (UNEP) (2009) *Fisheries and Aquaculture in Our Changing Climate*. Multiagency Policy Brief.
- United Nations Framework Convention on Climate Change (UNFCCC-COP) (2009) Conference of Parties. 15th Session 2009, Proceedings. Geneva, Switzerland.